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REPORT R-1777

COMPUTER, GUN DIRECTION, M18 (FADAC)
APPLICABILITY IN DEFENSE COMMUNICATION SATELLITE
ANTENNA POSITIONER SYSTEM

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HELEN SMOLEN

AMCMS Code 5331.12.918
DA Project No. 1R322101D253

October 1965



**UNITED STATES ARMY
FRANKFORD ARSENAL
PHILADELPHIA, PA.**

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by

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**AMCMS Code 5331.12.918
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**Fire Control Engineering Directorate
FRANKFORD ARSENAL
Philadelphia, Pa. 19137**

October 1965

FOREWORD

The study described in this report was performed by the U. S. Army, Frankford Arsenal, Philadelphia, Penna. The work was accomplished under DA Project No. 1R322101D253. Mr. A. Chalfin, of the Diagnostic and Direction Systems Engineering Branch, Fire Direction and Diagnostic Equipment Division (FDDE) was the Frankford Arsenal Project Director.

The study was performed from December 1964 to July 1965 by H. Smolen of the Computer Programming and Analysis Branch, FDDE Division.

The technical assistance of Mr. J. Junier is gratefully acknowledged.

ABSTRACT

The study described in this report was undertaken at the request of the U. S. Army Satellite Communications Agency, Ft. Monmouth, N. J., to determine the suitability of Computer, Gun Direction, M18 (FADAC), as the control unit in an Antenna Position Programmer System designed to acquire and track earth satellites.

Results of the study show that FADAC has the capability of performing the required functions, can interface with the remainder of the system, and, at operator's option, either output control data to the antenna positioner within the real time specified, or generate a punched paper tape.

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INTRODUCTION

At the request of the U. S. Army Satellite Communications Agency, Ft. Monmouth, N. J., a study was undertaken to determine the suitability of Computer, Gun Direction, M18 (FADAC) as the control unit in an Antenna Position Programmer System designed to acquire and track earth satellites. "Suitability" was defined as the ability of FADAC to operate in each of two modes, as follows:

1. MODE I - Real Time Mode

Given input parameters which define start time, the location of the ground link control station and the motion of the satellite, compute required azimuth (AZ) and elevation (EL) angles at which the antenna must be fixed to initiate tracking; accept a time signal from an external source and output the computed parameters in electrical pulse form to the next stage of the system. Update time by 10 seconds, recompute AZ and EL, and compute the change in AZ and EL as a function of change in time (ΔAZ and ΔEL), and rate of change per 1/10 second ($\Delta AZ/100$ and $\Delta EL/100$). On receipt of the next time signal, output the computed parameters in a fixed order. Repeat the compute and output operations at 10-second real-time intervals over a 24-hour period, a total of 8640 times.

2. MODE II - Paper Tape Generator Mode

Given input parameters which define start time, the location of the tracking station and the motion of the satellite, compute the six parameters described in (1) above. Output a properly formatted Time Identification Line, followed by the six time-associated parameters, to a 5-level paper tape punch unit. Update time by 10 seconds, recompute the 6 parameters, output an updated Time Identification Line and the 6 parameters, until 8640 sets of data (1 set for each 10-second interval over a 24-hour period) have been punched on paper tape.

In the Real Time Mode, execution time is critical, since after receipt of the first externally generated time signal, all operations described in (1) above must be completed in less than 10 seconds. Therefore, a major objective of the study was to devise a realistic measure of FADAC execution time in this mode. Toward this end, a program was designed and partially coded in FADAC mnemonics. The program was extended to include the Paper Tape Generator mode, to assure that all compute, interface, control, and tape generation problems were studied.

The software design should be considered a suggested approach to the solution of these problems, and represents only one of many possible approaches which could have been considered, given the tentative specifications which were provided at the time the study was initiated. In future final design of the computer program, system hardware must be fully defined.

DESCRIPTION OF FADAC

General

FADAC is a solid state, general purpose, digital computer designed to perform 12,500 additions or subtractions per second, and 711 multiplications or divisions per second. The computer has a rotating disc memory (1 disc revolution per 10 milliseconds) of 8192 fixed point words, each containing either a sign bit plus 31 magnitude bits, or a 32 bit instruction. Each instruction word contains the addresses of the operand and of the next command (a 1 + 1 system). The high speed operation of FADAC is a function of optimum coding and a unique multiplexing feature. Given minimum access coding, hardware design allows simultaneous, (1) operand read of the preceding instruction, (2) execution of the preceding instruction, (3) instruction read of the current instruction, (4) operand search of the current instruction, and (5) instruction search of the next instruction, all within one word time (78 micro-seconds). (Commands requiring more than one word time for execution delay computation by this additional execution time). The multiplexing characteristic of FADAC operation greatly increases its usefulness in real-time applications. Complete programming specifications are contained in Revision 1, Vol. IV of the Frankford Arsenal Notes on Development Type Materiel, FCDD-361, November 1962.

Input/Output

Input: Input to the computer is from the manual keyboard or the mechanical tape reader located on the control panel. External sources may be used to load the computer, such as:

a. Reproducer, Signal Data, AN/GSQ-64, which is a high speed photoelectric reader, designated the Memory Loading Unit (MLU). (Input at approximately 600 char/sec.)

b. Another FADAC

c. Gunnery Officer's Console

d. Other Fielddata or Teletype Equipment

e. Magnetic Tape Unit

Either Fielddata or Teletype code may be input, with automatic conversion to machine language.

Output: Output may be in the form of a visual display through the Nixie Tubes on the FADAC control panel, or to external output equipment such as:

1. Gunnery Officer's Console

2. Another FADAC

3. Battery Display Unit

4. Printer

5. Paper Tape Punch Unit

6. Magnetic Tape Unit

7. Other Fielddata or Teletype Equipment.

Output may be in Fielddata, 5-level teletype or 2-wire teletype codes, at rates of from 60 to 4000 char./sec., depending on the equipment used.

GENERAL PROGRAM DESCRIPTION

Figure 1 is a general flow diagram of the overall computer program developed to control both the Real Time and Paper Tape Generator Modes of operation. Note that the Initialization and General Computation Routines are common to both operating modes. To start the program, the SET-UP button is pressed, the Initialization Routine is executed and FADAC halts to allow the operator to select the desired operating mode. The COMPUTE button is depressed to select the Real Time Mode (RTM). The SEND button is depressed to select the Paper Tape Generator Mode (PTGM). The mode selected is reflected in the value stored in the programmed branching point (SW2). After SW2 is set, the program will automatically go through the General Computation Routine, test the value of SW2, generate the required output in a fixed order, update time, recompute the time-dependent equations 3 through 11, and repeat the cycle through a real (Mode I) or simulated (Mode II) 24 hour period.

The Initialization Routine is described in the flow diagram of figure 2. In this routine are preset the various indicators and addresses which control the paths through the program and the input of data. Start-time is input through FADAC keyboard and displayed; after which the fourteen input parameters defined in Table I are automatically read-in through the Mechanical Reader on the FADAC control panel. All inputs are converted from BCD to binary and stored.

A detailed flow-diagram of the General Computation Routine is shown in figure 3. The routine, coded in FADAC mnemonics, is contained in Appendix B. The mathematical equations used in the demonstration program were provided by the Satellite Communications Agency, and are shown in figure 3. Symbols used in the General Computation Routine (GCR) are defined in Table I and Appendix D.

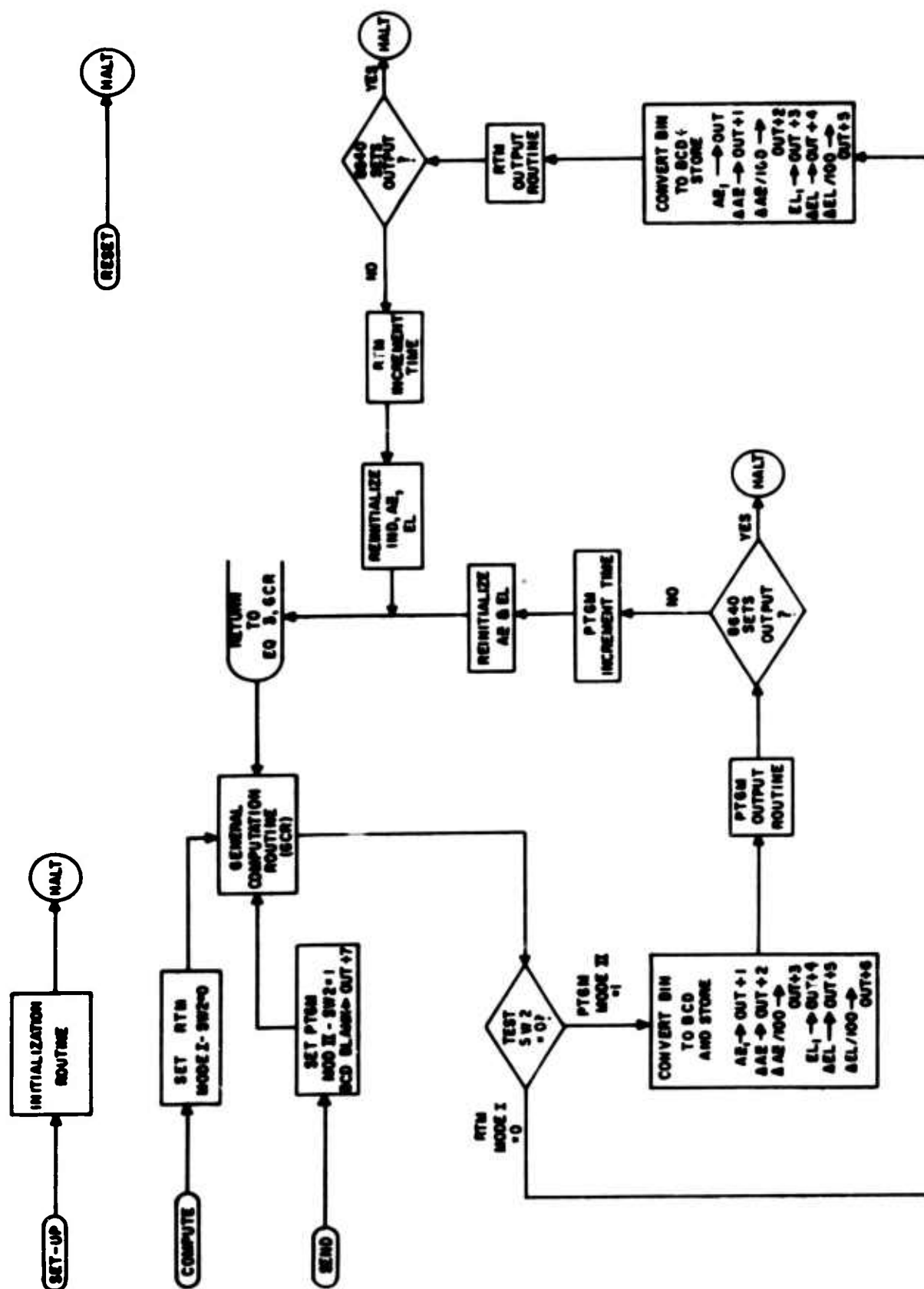


Figure 1. General Flow Diagram-Antenna Position Programmer System

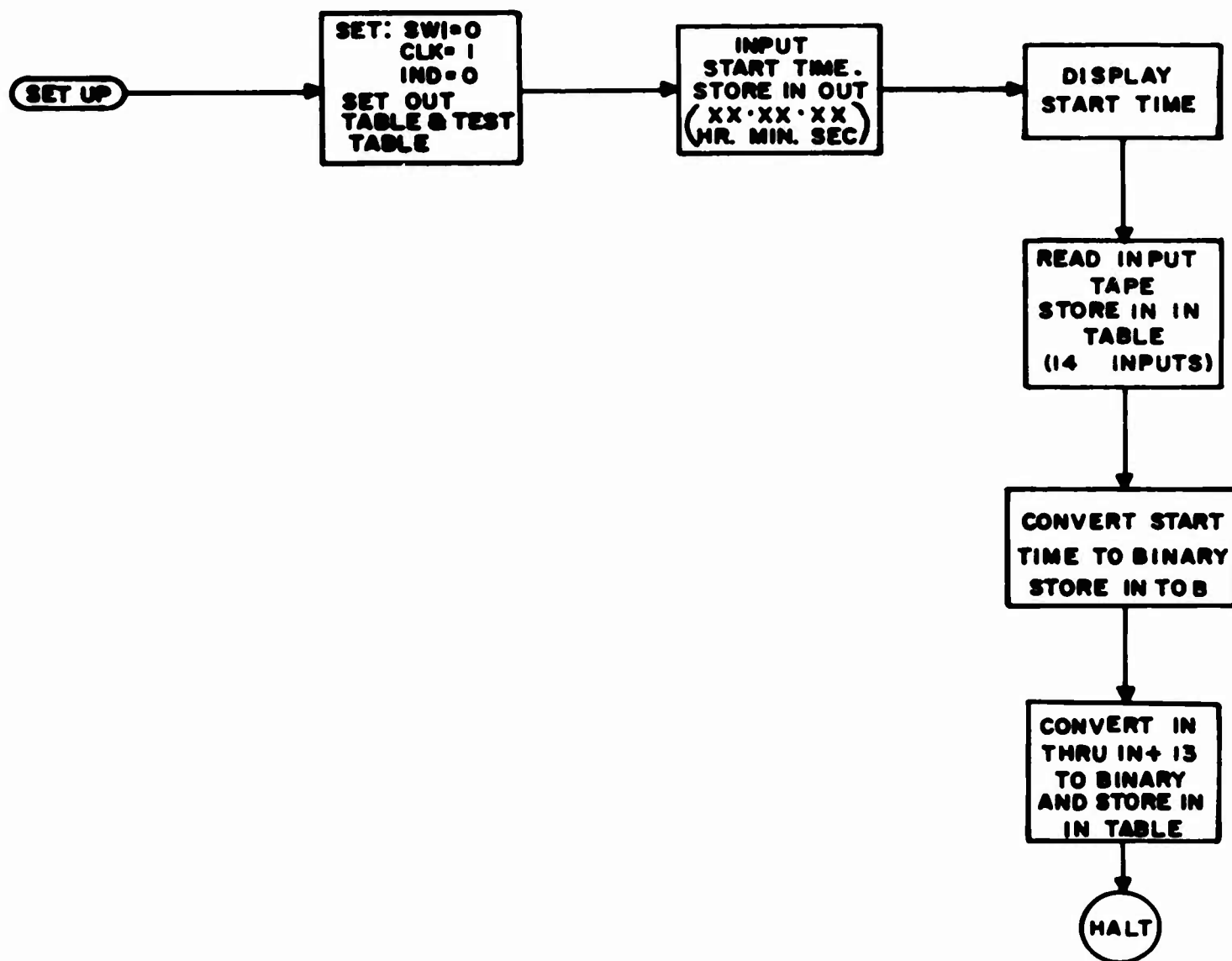


Figure 2. Flow Diagram-Initialization Routine

Table I. DEFINITION OF INPUTS

| <u>"In" Table</u> | <u>Symbolic Notation as shown on Program Listing</u> | <u>Symbolic Notation as shown on Flow Diagrams</u> | <u>Definition</u> |
|-------------------|--|--|--|
| In | THDS | ϕ_{ds} | Geodetic latitude |
| In + 1 | HS | HS | Height of station above sea level |
| In + 2 | REE | R_e | Equatorial earth radius |
| In + 3 | LAMS | λ_s | Geodetic longitude |
| In + 4 | OI | OI | Orbital inclination |
| In + 5 | DELO | $\Delta \Omega$ | Nodal Motion |
| In + 6 | DELC | $\Delta \psi$ | Perigee Motion |
| In + 7 | PA | PA | Anomolistic Period |
| In + 8 | MO | MO | Mean anomaly at epoch |
| In + 9 | EORB | E_{orb} | Orbital eccentricity |
| In + 10 | ANOM | ANOM | Semi-major axis normalized to R_e |
| In + 11 | CHIO | ψ_o | Argument of perigee at epoch |
| In + 12 | PHRA | PHRA | Right ascension of ascending node at epoch |
| In + 13 | GHAR | GHAR | Greenwich hour angle of Aries at epoch. |

NOTE: In through In + 13 are stored in 14 contiguous locations in FADAC memory.



Figure 3. Flow Diagram-General Computation Routine (GCR)

DETAILED DESCRIPTION OF REAL TIME MODE

Hardware Considerations

FADAC operation in the Real Time mode will require the following peripheral equipment:

- (1) A high speed Memory Loading Unit (MLU) which is used to load the program into FADAC.
- (2) A timer, which will generate a signal every 10 seconds.
- (3) An Output Buffer, which is to be designed to accept BCD code generated by FADAC and transmit it to the six antenna position control channels.
- (4) A Remote Display Unit (RDU).

FADAC is designed to transmit data information over 5 data lines (for Teletype code) or 8 data lines (for Fielddata code), in parallel by character. In addition, six output control lines (OPL-1 thru OPL-6) are available to set or reset any desired external devices. In the Antenna Positioner System these six lines may be connected through the Output Buffer to each of the six position control channels. Thus, under program control, FADAC will transmit a given data word to a particular channel. However, this method would limit the number of output channels which can be controlled to the six output control lines available. As an alternative, the Output Buffer may contain a 6-position electronic stepping switch (or n-position, if additional control channels are required) designed to interpret a signal on one FADAC output line (OPL-1) as a command to reset the electronic switch to switch position 1, and to interpret a signal on a second FADAC output line (OPL-2) as a command to step through to the next switch position in sequence. The latter output buffer logic is assumed in the model program. (Note that the use of all six output control lines would not significantly affect the results in terms of execution time, or program complexity.)

BCD data will be transmitted from FADAC through the stepping switch to the particular antenna position channel defined by a given switch position, as shown in the following table:

| <u>With the Stepping Switch in Position No.</u> | <u>Data is Transmitted to:</u> |
|---|--------------------------------|
| 1 | AZ Channel |
| 2 | Δ AZ Channel |
| 3 | Δ A Z/100 Channel |
| 4 | EL Channel |
| 5 | Δ EL Channel |
| 6 | Δ EL/100 Channel |

The logic assumed in this study requires the use of only two output control lines (OPL-1 and OPL-2)*freeing the remaining four lines for the control of other peripheral equipment.

Given an output command, FADAC hardware requires that a feedback signal be received by the computer after the output of each character. Failure to receive the feedback signal will halt output. In the design of the Output Buffer, either of two feedback methods may be used:

(1) **External Feedback:** Include a strobe feedback network in the design of the Output Buffer such that a feedback signal will be sent to the computer after each BCD character is received.

(2) **Free-running:** Wire the FADAC strobe network to accept its self-generated strobe as the required feedback after each character is transmitted. This does not require a change to FADAC hardware, since there is external access to the computer's feedback network through the J-10 output connector.

Figure 4 is a block diagram of the equipment required for FADAC operation in the Real Time Mode. The directed lines indicate the direction of data flow.

* A signal on OPL-1 is generated by an OD-1 command, on OPL-2 by an OD-2 command.

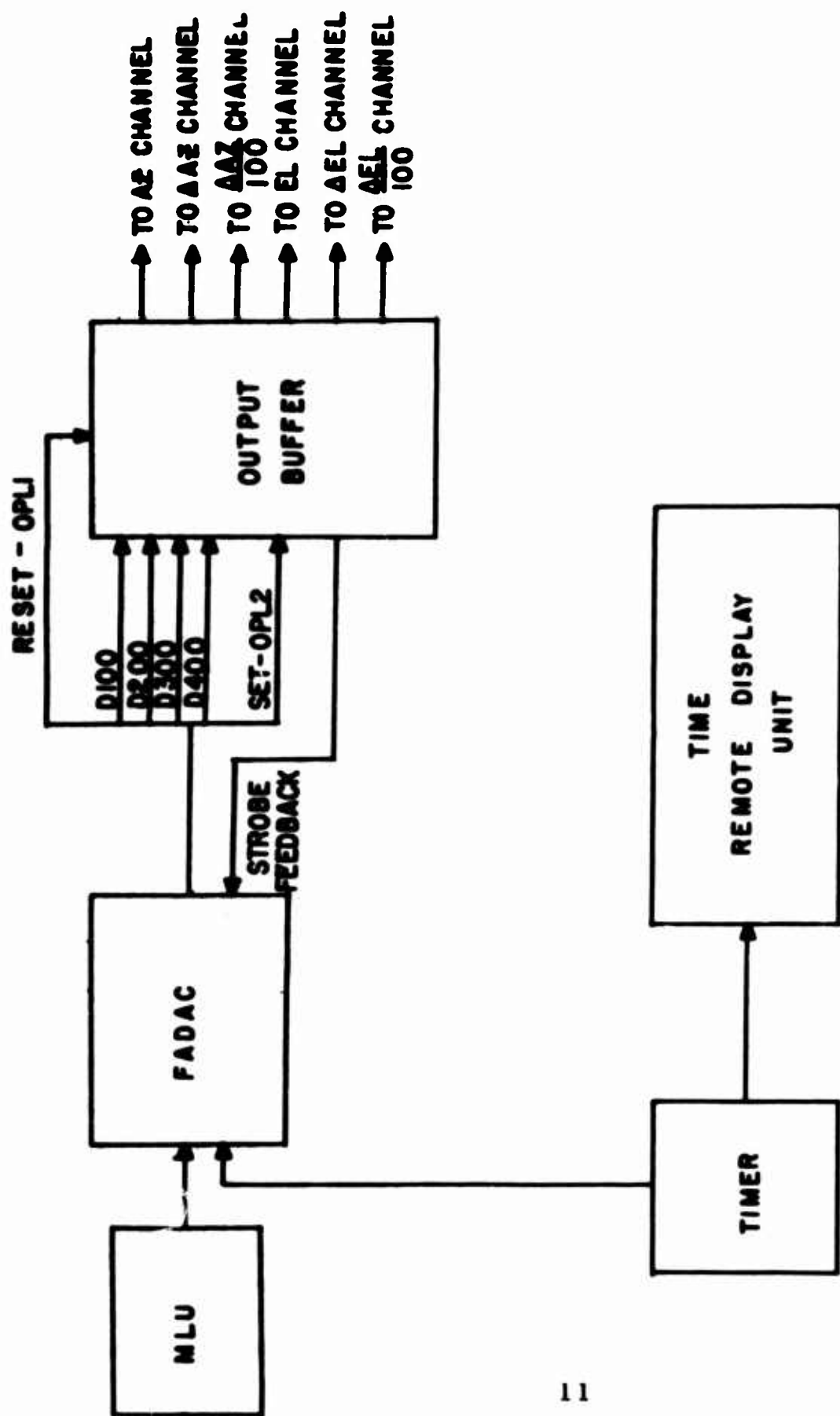


Figure 4. Block-Diagram of Equipment Required - Real Time Mode

Output Routine

A detailed flow diagram of the Real Time Mode Output Routine is contained in figure 5. To expedite output, the so-called "Out" and "Test" tables set by the Initialization Routine are stored in the R and Q loops respectively. Since output is by character rather than by word, the integrity of the contents of the two high speed loops is unaffected by the output commands. A listing of the mnemonic codes for the "Out" and "Test" loops, and the reinitialization of these loops, is contained in Appendix B.

Output Codes

FADAC will output BCD in either Baudot (TT) or Fielddata (FD) code. Study of the FD code showed that the four least significant bits of the eight bit FD code generated for decimal digits 0 through 9, and the decimal point, exactly duplicate the BCD codes for these characters. However, the FD codes for plus and minus are not equivalent to the BCD configuration.

It is assumed in this report that the RTM-Binary to BCD conversion routine contains a test for sign such that, if the sign is plus, the conversion routine is coded to generate four zero bits; if minus, the routine is coded to generate four one bits, rather than the BCD plus code (1010) or minus code (1011). Thus, in the RTM Output Routine, the sign of each parameter is tested with a single TPL command. If plus, an FD "U" is output (the four least significant bits of which are 1010); if minus, an FD "V" is output (the four least significant bits which are 1011). (See figure 5 - RTM Output Routine and Appendix B - Program Listing.) With the FADAC data lines D100 through D400 connected to the Output Buffer, and lines D500 through D800 open, BCD code can be transmitted through the electronic stepping switch circuit to a given antenna position control channel.

If higher output speeds are desired, output can be in the Alpha-4 mode rather than in Fielddata BCD. However, in the ALPHA -4 mode only 4 characters can be stored per FADAC word. It would therefore be necessary to use two FADAC locations for each 8-character word output. (It was assumed that the six output parameters could be adequately defined by 6 decimal digits, a decimal point and a sign, a total of 8 characters per output.) Also a conversion routine from binary to the desired Alpha -4



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configuration would be required. However, this output mode should be considered if it is desired to form a special 8-bit code, 3 bits of which may be used to identify the control channel to which the data word is to be sent, 4 bits to define a BCD coded digit, decimal point or sign; and 1 bit of which may be suppressed by the receiving device. Fielddata BCD output is used in the demonstration program. FADAC output speeds for the two modes are as follows:

- (1) BCD is transmitted at the rate of 650 char/sec.
- (2) Alpha-4 is transmitted at the rate of 4000 char/sec.

Note that if FADAC is wired to generate its own feedback signal, (free running) the Output Buffer must accept data at a rate greater than the rate at which characters are output by FADAC.

Timing Estimate

To provide a basis for realistically estimating the time required to execute the FADAC program designed for the Real Time Mode (RTM) operation, the following elements of the program were coded in FADAC mnemonics:

- a. General Computation Routine (GCR) (fig. 3)
- b. RTM Output Routine (fig. 5)

Subroutines for the trigonometric functions, square root, BCD to Binary and Binary to BCD conversions, and special formats were not coded since the execution time of existing versions of similar or identical routines was known, or could be estimated.

A FADAC word time is 78 micro-second; a disc revolution, 10 milliseconds. Most instructions require one word-time for execution; while a STR, MPY, and DIV require 18-word times, and a LDR and LDQ require 16-word times. (See Appendix C for list of FADAC mnemonics.)

Execution time for each element coded was calculated as follows:

Let

X = Number of instructions per routine or equation

$Y = 78 \times 10^{-6}$ sec = 1 word-time

ΣY = Total minimum number of word times per routine or equation, in seconds

Z = Time required to execute each subroutine transferred to within each program element, in seconds

N = Total number of transfers to subroutines within each program element

$D = .010$ seconds = 1 disc revolution time

Then, Total execution time per program element

$$= \Sigma Y + \Sigma Z + (X/2)(D) + N(D)$$

Where the factor $(X/2)D$ is a worst case factor which was added to the estimated execution time to compensate for access time and scaling considerations which were not included in the sample coding. The factor $N(D)$ is an additional worst case factor which allows an entire disc revolution lost for each transfer to a subroutine.

To illustrate, the time required to set SW2 and execute Eq 1 was as follows:

$$X = 49$$

$$(X/2)D = 25 \times (.010) = .250 \text{ sec}$$

Subroutines:

Sin/Cos used twice at .020 ea = .040

Tan used once at .010 ea = .010

Arc tan used once at .030 ea = .030

$$\begin{aligned} \Sigma Z &= .080 \text{ sec} \\ N(D) &= 4(.010) = .040 \text{ sec} \\ \Sigma Y &= 236(78 \times 10^{-6}) = \underline{.018 \text{ sec}} \\ \text{Total Eq 1} &= .388 \text{ sec} \end{aligned}$$

Note that ΣY was based on 38 one-word time instructions plus 11 eighteen-word time instructions, a total of 236 word times.

Subroutines called by the program were assumed to require the following execution times:

| <u>Routine</u> | <u>Time in Seconds</u> |
|--------------------------|------------------------|
| BCD to Bin | .010 sec/char |
| Bin to BCD | .010 sec/char |
| Sin/Cos (both solutions) | .020 sec |
| Arc Sin | .030 sec |
| Arc Tan | .030 sec |
| Tan | .010 sec |
| Square Root | .010 sec |

A summary of the estimated worst-case time required to execute all elements of the Real Time operating mode is contained in Table II. Note that execution time of the Initialization Routine is not included, since this routine is completed prior to entry into the Real Time operations.

DETAILED DESCRIPTION OF PAPER TAPE GENERATOR MODE

Hardware Considerations

Peripheral equipment required for FADAC operation in the Paper Tape Generator Mode is illustrated in the block diagram of figure 6. A commercially available 5, 7 or 8 level paper tape punch unit is connected to FADAC data lines through an appropriate interface. (Note that FA personnel have designed such an interface network for the Soroban Model LP-2 Paper Tape Punch Unit.)

Output Codes

The Satellite Communications Agency has indicated that any code may be used for the Tape Generator Mode which is less than 8 bits per

**Table II. SUMMARY OF TIME REQUIRED TO EXECUTE FADAC
PROGRAM FOR THE REAL-TIME OPERATING MODE**

| <u>Program Element</u> | <u>Estimated Execution Time (in seconds)</u> |
|--|--|
| Set SW2 and Execute Eq 1* | 0.388 |
| Eq 2 | .160 |
| Eq 3 | .043 |
| Eq 4 | 1.037** |
| Eq 5 | .127 |
| Eq 6 | .150 |
| Eq 7 | .033 |
| Eq 8 | .180 |
| Eq 9 | .055 |
| Eq 10 | .363 |
| Eq 11 | .218 |
| Linkage to RTM and Conversion to BCD | .764 |
| RTM Output Routine | .416 |
| Increment Time, Reinitialize AZ0, AZ1, E10, E11, and Return to Eq 3 | <u>1.400</u> |
| Total | 5.334 |

*Equations 1 through 11 constitute the General Computation Routine

**Assuming ten iterations

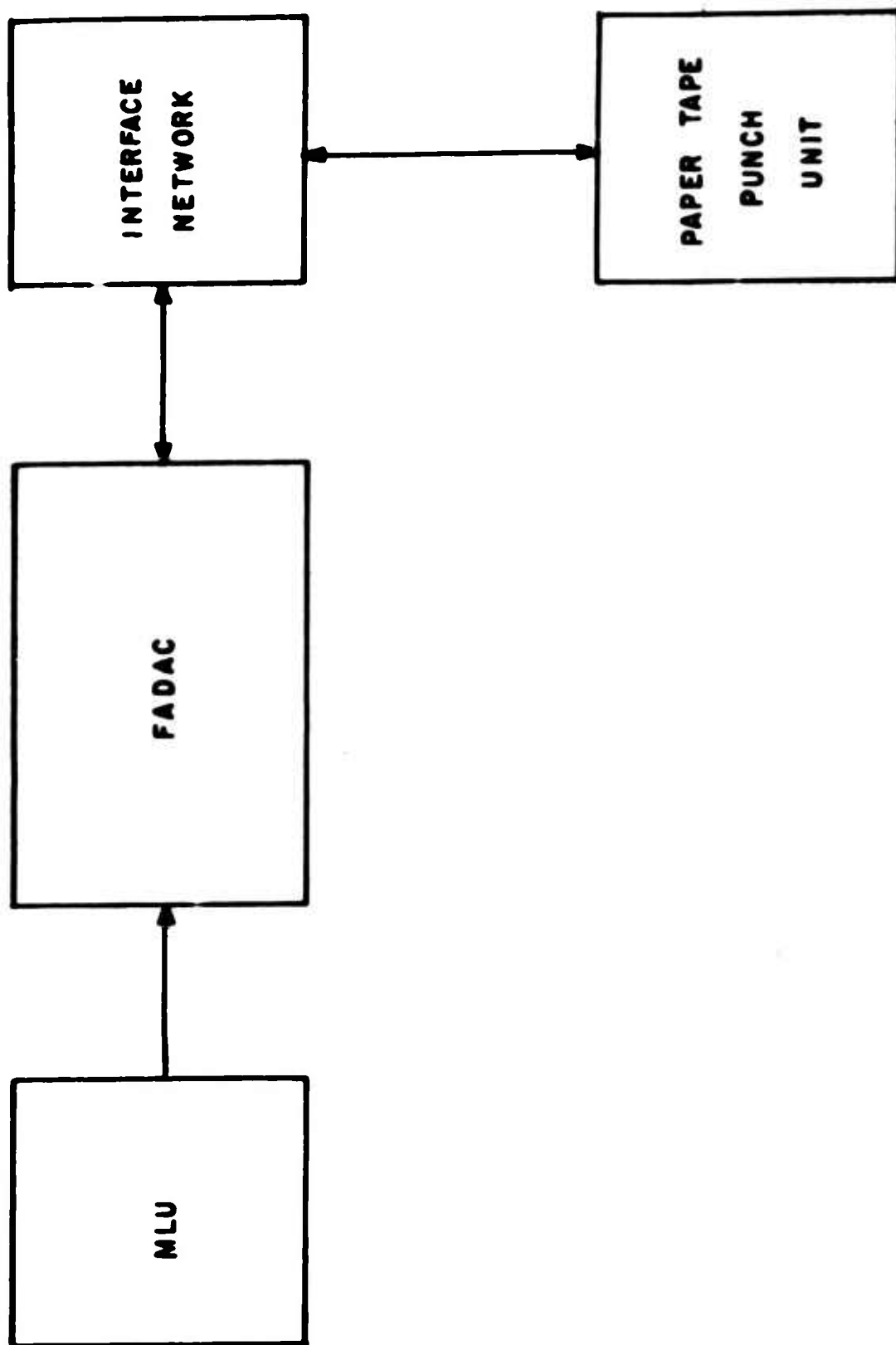


Figure 6. Block Diagram of Equipment Required - Paper Tape Generator Mode

character, to allow space on 8-level tape for the simultaneous print and punch of each character output. In the demonstration program, output is by word in 5-level (TT) code. It is assumed that since FADAC will not be used to control the Paper-Tape Track mode of operation, * equipment which is to be designed for this mode will be capable of decoding the 5-level tape code and generating the BCD code (or other format) desired. As an alternative to the 5-level code suggested in the demonstration program, the special 8-bit code described on p. 14 may be used. The first bit can be stripped by leaving data line D800 open, the channel-identifying 3-bits transmitted over lines D700 through D500, and the 4-bit BCD code transmitted over lines D400 through D100. Again, it will be necessary to design a special conversion routine and output by character in the high-speed Alpha-4 mode.

7

Special Features of the Mode II Program

Note that in the General Initialization Routine (fig. 2) start-time is entered through FADAC keyboard in BCD, and stored directly into location "Out". This quantity is ignored during output in the Real Time Mode. However, start-time is an important element in the Tape Generator Mode, since it is updated at 10-second intervals and serves as the Time Identification Line for each set of data output. A "set of data" is defined as the following parameters: (1) Time Identification Line, (2) AZ, (3) Δ AZ, (4) Δ AZ/100, (5) EL, (6) Δ EL, (7) Δ EL/100, (8) one word of BCD blanks. After the initial set is transmitted to the tape punch unit, time is up-dated by 10 seconds, and the new value of time stored in location "Out" in BCD, and in "TOB" in binary. See figure 7.

When the Tape Generator Mode is selected by depression of the SEND button, the programmed branching point (SW2) is set to output in Mode II, and location "Out + 7" is filled with BCD blanks. The blanks will generate a space (8-sprocket holes) between each set of data to assure that no characters will be lost when the tape is used as the source of data in the so-called Paper Tape Track mode.*

Tape Considerations

Normally, FADAC programs are punched on fanfold 5-level or 8-level paper tape, 1000 feet in length. This length is more than adequate for a program which will fill FADAC memory, since the tape will hold 10

*Described in Satellite Communications Agency Report 1011, 12 Jan 1965, FAPS.

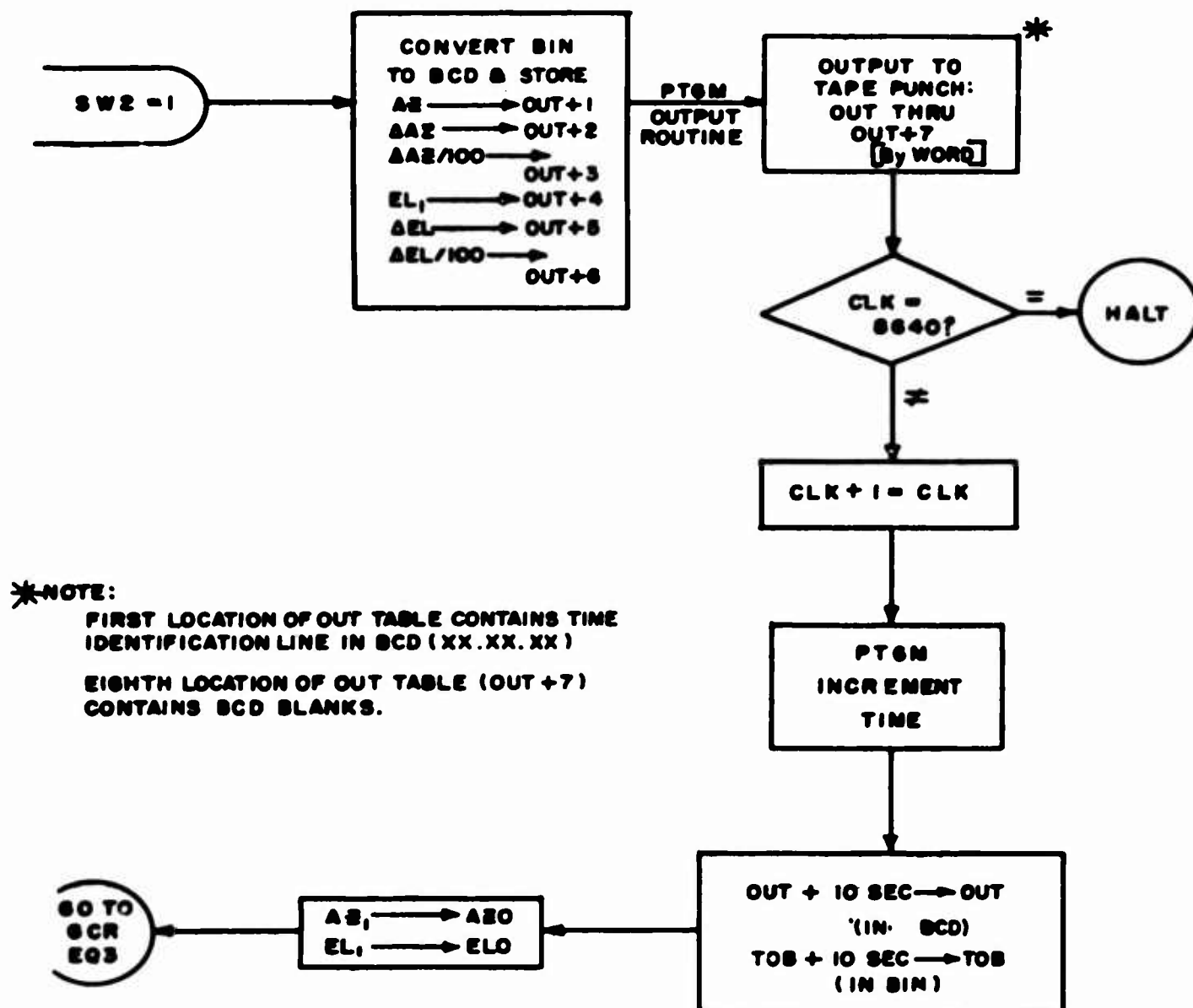


FIG 7 - FLOW DIAGRAM-PAPER TAPE GENERATOR MODE OUTPUT ROUTINE (PTGM)

Figure 7. Flow Diagram - Paper Tape Generator Mode Output Routine (PTGM)

characters per inch (120,000 char/tape). However, the tape generated during Mode II operation must contain 8640 sets of data, with each set made up of 64 characters, a total of 552,960 characters. Thus a tape for one 24-hour period must be greater than 4608 feet long. This problem was discussed with a tape manufacturer, who stated that he could not produce fan-folded tape in 5000-foot lengths, since it would be impossible to handle. Rolled paper tape was recommended. A motor driven jig can be designed to fix rolled tape reels to the MLU, and re-roll the tape as it passes beyond the read heads. As an alternative, many high-speed paper tape readers, designed to handle rolled paper tape, are commercially available.

CONCLUSIONS

The study proved that FADAC can perform all the required functions in both the Real Time and the Paper Tape Generator Modes.

The study proved that in the worst case, less than six seconds real time is required to allow FADAC to compute and transmit control data to the Antenna Position Control Channels. Therefore, the real time intervals specified for operation in the Real Time Mode can be significantly reduced.

RECOMMENDATIONS

In a review of the 11 equations solved to determine current values of AZ and EL, it was noted that Equation 9 of the General Computation Routine, "Above Horizon Determination", appears to serve no purpose. This equation calls for the solution of the product $RS.RG$. Guidance received from the Satellite Communication Agency indicated that if $RS^2 \leq RS.RG$, then the Satellite is above the horizon. However, there is no requirement to test

this relationship, or in any way change the computations or output regardless of the value of RS , RG . It is therefore recommended that this equation be deleted from the final version of the General Computation Routine.

It is recommended that rolled paper tape be used in the final version of this program. It is further recommended that the use of a commercially available high-speed paper tape reader, other than the MLU, be investigated.

APPENDIX A

CONVENTIONS USED IN CODING

1. All symbols begin with an alphabetic character, contain no less than 2 characters, either alphabetic or numeric (except when a register A, L or N, is referenced) and no more than 4 characters.

2. The coding format is as follows:

LOCATION Field - OP-CODE - OP Address, NI Address

3. The blank addressing, symbolic, and other coding conventions used are explained in the following example:

- | | | | |
|----|----|-----|---------------|
| 1. | Go | CLA | In + 5 |
| 2. | | MPY | KO |
| 3. | | ADD | |
| 4. | | DEC | 0.023 |
| 5. | | TPL | Go, No |
| 6. | No | ADD | In |
| 7. | | STA | Out + 2, Able |

Interpretation of Example:

Instruction (1): The Lo Field is labelled "Go". The Op Address "In + 5" references the sixth location in a table labelled "In" where "In" is the first location of the table, "In + 1", the second, etc. The blank NI is interpreted as "go to the next instruction in sequence", here Instruction (2).

Instruction (2): Multiply the contents of the A register by the value contained in the location labelled KO, and go to Instruction (3).

Instruction (3): Add the contents of Instruction (4) to the A register and go to Instruction (5). (Note that an instruction containing a blank Op Address is always followed by a decimal quantity. If both the Op Address and NI are blank, then the Op Address is interpreted as the next instruction in sequence and the NI is the next instruction plus 1.)

Instruction (4): The decimal quantity referenced in (3) and designated by the psuedo Op code "DEC".

Instruction (5): Test for plus; if plus, go to the location labelled "Go", if not, go to "No".

Instruction (6): Location "No" contains the command "add the contents of the first location of the table labelled 'In'", and go to Instruction (7).

Instruction (7): Store A in the third location of the table labelled "Out" and go to the location labelled "Able".

APPENDIX B

PROGRAM LISTING - REAL TIME MODE

| | | | |
|------|------|-----------|-----------------------------------|
| COMP | TRA | SETQ | |
| SETQ | ZEL | | SET SW2 |
| | STL | SW2, GCR | GO TO GENERAL COMPUTATION ROUTINE |
| GCR | CLA | IN | EQUATION 1 THDS TO A |
| | TRA* | TAN | TRANSFER TO TAN ROUTINE |
| | STA | TAND | TAN THDS |
| | MPY | | |
| | DEC | 0.9999887 | |
| | TRA* | A TAN | ARCTAN ROUTINE |
| | STA | THCS | |
| | TRA* | SINC | SIN/COS ROUTINE |
| | STL* | COTC | COS(THCS) TO A TO COTC |
| | STA | SITC | SIN(THCS) |
| | CLA | N | |
| | MPY | N | |
| | STA | SOCT | \cos^2 THCS |
| | CLA | | (1) |
| | DEC | 18_ | |
| | STA | 0.1 | |

| | | |
|-----|--------|--|
| ZEL | | |
| DIV | | (297) |
| DEC | 2978 | |
| STA | D.0 | (1/297 TO D.0) |
| CLA | D.1 | |
| SUB | D.0 | (1-1/297):AB |
| STA | D.1 | AB TO D.1 |
| MPY | D.0 | |
| MPY | 30CT | |
| ADD | D.1 | $AB + (1/297(AB)(\cos^4 \theta_{HCS})) : RE/REE$ |
| STA | D.0 | RE/REE TO D.0 & RERE |
| STA | RERE | |
| CLA | IN + 1 | (HS) |
| ZEL | | |
| CLD | IN + 2 | HS/REE:HSRE |
| STA | HSRE | |
| ADD | D.0 | $HS/REE + RE/REE : RS$ |
| STA | RS | |
| STA | D.1 | RS TO D.1 |
| CLA | IN + 3 | LANS |

| | | | |
|-----|------|---------|------------------------------|
| | TRA* | SINC | |
| | STA | SILA | SIN LAMS |
| | STL | COLA | COS LAMS |
| | MPY | COTC | |
| | MPY | D.1 | |
| | STA | YS | RS(SIN LAMS . COS THCS) : YS |
| | CLA | D.1 | |
| | MPY | COTC | |
| | MPY | COLA | |
| | STA | XS | RS(COS THCS . COS LAMS) : XS |
| | CLA | D.1 | |
| | MPY | SITC | |
| | STA | ZS, EQ2 | RS(SIN THCS) : ZS |
| EQ2 | CLA | K0 | EQUATION 2 |
| K0 | DEC | 1440B | |
| | MPY | K1 | |
| K1 | DEC | 360B | K0(K1) : K2 |
| | STA | D.1 | K2 TO D.1 |
| | CLA | IN + ' | QI TO A |
| | TRA* | SINC | |

| | | | |
|------|-----|----------|---|
| | STA | SIOI | SIN OI |
| | STL | COOI | COS OI |
| | CLS | L | -COS OI TO A |
| | MPY | IN + 5 | DELO |
| | SUB | IN + 6 | DELC |
| | MPY | IN + 7 | PA TO N |
| | MPY | N | |
| | STN | D.0 | PA TO D.0 |
| | ZEL | | |
| | DIV | K2 | $(((-\cos OI)(DELO) - DELC)PA^2)/K2) +$ |
| | ADD | D.0 | $+ PA =$ |
| | STA | PK | $= PK$ |
| | STA | D.1, EQ3 | PK TO A AND D.1 |
| EQ3 | CLA | TOB | TIME IN MINUTES (EQUATION 3) |
| | ZEL | | |
| | DIV | D.1 | |
| | MPY | KI | $360(TOB)/PK$ |
| | ADD | IN + 8 | MO |
| | STA | MA, | $(360(TOB))/PK + MO : MA$ |
| ITER | STA | D.1, EQ4 | MA TO D.1 (LET MA : EJ) |

| | | | |
|-----|------|-----------|---|
| FC4 | TRA* | SINC | |
| | MPY | IN + 4 | (SIN EJ) (EORE) |
| | MPY | | |
| | DEC | 57.295773 | 180/PI |
| | ADD | D.1 | EJ |
| | STA | D.0 | EJ+1 : (SIN EJ(EORE)180/PI) + (EJ), EJ+1 TO D.0 |
| | SUB | D.1 | |
| | ABS | A | /EJ+1-EJ/ |
| | SUB | | |
| | DEC | 0.01 | |
| | TZE | EQU, NOT | |
| EQU | CLA | D.0 | EJ+1 |
| | STA | EFIN, E05 | |
| NOT | TPL | , EQ | |
| | CLA | D.0, ITER | (STORE EJ+1 IN EJ) |
| E05 | TRA* | SINC | EFIN IS IN A |
| | STA | SIEF | (SIN EFIN) |
| | STA | D.0 | SIN EFIN TO D.0 |
| | STL | COEF | COS EFIN |
| | CLA | L | COS EFIN TO A |

| | | | |
|-----|------|----------|---|
| | SUB | IN + 9 | EORB |
| | MPY | IN + 10 | ANOM |
| | STA | X1 | (COS EFIN - EORB)ANOM : X1 |
| | CLA | EORB | |
| | STA | D.1 | EORB TO D.1 |
| | MPY | D.1 | |
| | CLS | A | |
| | ADD | ONE | $1 - (EORB)^2$ |
| | TRA* | SORT | SQUARE ROOT ROUTINE |
| | MPY | D.0 | SIN EFIN in D.0 |
| | MPY | IN + 10 | ANOM |
| | STA | Y1 | $(\sqrt{1 - EORB^2}) \sin EFIN \cdot ANOM = Y1$ |
| | STA | D.1, EQ6 | |
| EQ6 | CLA | IN + 6 | DELC |
| | MPY | TOB | |
| | ZEL | | |
| | DIV | KO | |
| | ADD | IN + 11 | CH10 |
| | STA | CH1 | DELC(TOB)/KO + CH10 : CH1 |
| | TRA* | SINC | |

| | | | |
|-----|-----|---------|---|
| | STA | SICH | SIN CHI |
| | STL | COCH | COS CHI |
| | MPY | D.1 | y_1 IN D.1 |
| | STA | D.0 | Y1(SIN CHI) TO D.0 |
| | CLA | X1 | |
| | MPY | COCH | |
| | SUB | D.0 | |
| | STA | X2 | $(-Y1(\text{SIN CHI}) + X1(\text{COS CHI})) : X2$ |
| | CLA | D.1 | y_1 IN D.1 |
| | MPY | N | (COS CHI IN N) |
| | STA | D.1 | Y1 COS CHI TO D.1 |
| | CLA | X1 | |
| | MPY | SICH | |
| | ADD | D.1 | |
| | STA | Y2, EQ7 | $Y1 \text{ COS CHI} + X1 \text{ SIN CHI} : Y2$ |
| EQ7 | STA | D.1 | Y2 TO D.1 |
| | MPY | COOI | COS OI |
| | STA | Y3 | $Y2(\text{COS OI}) : Y3$ |
| | CLA | D.1 | |
| | MPY | SIOI | SIN OI |

| | | | |
|-----|------|----------|---|
| | STA | Z3, EQ8 | Y2(SIN 01) : Z3 |
| | | | NOTE X2 EQUALS X3 |
| EQ8 | CLS | IN + 5 | (DELO) |
| | ZEL | | |
| | DIV | KO | KO : 1440 |
| | ADD | | |
| | DEC | 0.250683 | EARTH ROTATION RATE IN DEG/MIN (ΩE) |
| | MPY | TOB | |
| | SUB | IN + 12 | PHRA |
| | ADD | IN + 13 | GHR |
| | STA | PHI | |
| | TRA* | SINC | |
| | STA | SIPH | |
| | STA | D.0 | SIN PHI TO D.0 |
| | STL | COPH | |
| | STL | D.1 | COS PHI TO D.1 |
| | MPY | Y3 | Y3 TO N |
| | STA | R.0 | Y3(SIN PHI) TO R.0 |
| | CLA | D.1 | |
| | MPY | N | |

| | | | |
|-----|-----|---------|-------------------------------|
| | STA | R.2 | Y3(COS PHI) TO R.2 |
| | CLA | D.1 | |
| | MPY | X3 | X3 TO N |
| | STA | R.4 | X3(COS PHI) |
| | CLS | D.0 | |
| | MPY | N | (-X3(SIN PHI)) |
| | ADD | R.2 | |
| | STA | Y4 | Y3 COS PHI - X3 SIN PHI : Y4 |
| | CLA | R.4 | |
| | ADD | R.0 | |
| | STA | X4, EQ9 | X3(COS PHI) + Y3 SIN PHI : X4 |
| | | | (NOTE.. Z3 : Z4) |
| EQ9 | MPY | XS | (X4)(XS) TO A |
| | STA | D.0 | TO D.0 |
| | CLA | ZS | |
| | MPY | Z3 | Z3 : Z4 |
| | STA | D.1 | (ZS)(Z4) TO D.1 |
| | CLA | YS | |
| | MPY | Y4 | Y4 TO N |
| | ADD | D.0 | |

| | | | |
|------|-----|------------|----------------------------------|
| | ADD | D.1 | $(YS)Y4 + (XS)X4 + ZS24 : RSRG)$ |
| | STA | RSRG, EQ10 | |
| EQ10 | CLA | COLA | COS LAMS TO D.0 |
| | STA | D.0 | |
| | MPY | N | Y4 IN N |
| | STA | R.0 | Y4(COS LAMS) TO R.0 |
| | CLA | SILA | SIN LAMS TO D.1 |
| | STA | D.1 | |
| | MPY | N | |
| | STA | R.3 | Y4(SIN LAMS) TO R.3 |
| | CLS | D.1 | |
| | MPY | X4 | X4 TO N |
| | STA | R.6 | -X4(SIN LAMS) TO R.6 |
| | ADD | R.0 | -X4(SIN LAMS) + Y4(COS LAMS): |
| | STA | X5 | : X5 |
| | STA | R.5 | |
| | CLA | D.0 | |
| | MPY | N | |
| | STA | R.10 | X4(COS LAMS) TO R.10 |
| | ADD | R.3 | |

| | | |
|-----|------|--|
| STA | R.4 | $X4(\cos LAMS) + Y4(\sin LAMS)$ TO R.4 |
| CLA | THDS | |
| TRA | SINC | |
| STA | R.11 | SIN THDS TO R.11 |
| STL | R.12 | COS THDS TO R.12 |
| MPY | COTC | $(\sin THDS)(\cos THCS)$ |
| STA | R.13 | TO R.13 |
| CLA | R.12 | COS THDS |
| MPY | N | |
| STA | R.14 | $(\cos THDS)(\cos THCS)$ |
| CLA | R.11 | |
| MPY | SITC | |
| ADD | R.14 | $+(\cos THDS \cos THCS) + (\sin THDS \sin THCS)$ |
| STA | R.15 | : R.15 |
| CLS | R.12 | |
| MPY | N | $-(\cos THDS)(\sin THCS) +$ |
| ADD | R.13 | $+(\sin THDS)(\cos THCS)$ |
| STA | R.16 | TO R.16 |
| CLS | R.4 | $-(X4 \cos LAMS + Y4 \sin LAMS)(\sin THDS)$ |
| MPY | R.11 | TO |

| | | |
|-----|------|--|
| STA | R.17 | R.17 |
| CLA | N | (SIN THDS) |
| MPY | Z4 | Z4 TO N |
| STA | R.2 | Z4 SIN THDS TO R.2 |
| CLA | N | (Z4) |
| MPY | R.12 | |
| STA | R.1 | Z4(COS THDS) |
| CLA | R.4 | (X4 COS LAMS + Y4 SIN LAMS) |
| MPY | N | |
| STA | R.7 | COS THDS(X4 COS LAMS + Y4 SIN LAMS) |
| CLA | R.16 | (SIN THDS COS THCS - COS THDS SIN THCS)(RERE)- |
| MPY | RERE | |
| ADD | R.17 | -(X4COS LAMS + Y4 SIN LAMS)(SIN THDS) + |
| ADD | R.1 | +Z4(COS THDS) : |
| STA | Y5 | :Y5 |
| STA | R.3 | Y5 TO R.3 |
| CLS | R.15 | -(SIN THDS SIN THCS + COS THDS COS THCS)(RERE) + |
| MPY | N | + |
| ADD | R.2 | + Z4 SIN THDS + |
| ADD | R.7 | + (X4 COS LAMS + Y4 SIN LAMS) COS THDS + |

| | | | |
|------|------|------------|---------------------------------------|
| | ADD | HSRE | ← HS/REE : |
| | STA | Z5 | : Z5 |
| | STA | R.12, EQ11 | Z5 TO R.12 |
| EQ11 | MPY | A | Z5 IS IN A |
| | STA | D.0 | $(Z5)^2$ TO D.0 |
| | CLA | R.3 | Y5 |
| | MPY | A | |
| | STA | D.1 | $(Y5)^2$ TO D.1 |
| | CLA | R.5 | X5 TO A |
| | MPY | A | $(X5)^2$ IN A |
| | ADD | D.0 | |
| | ADD | D.1 | |
| | TRA* | SORT | TRANSFER TO SQUARE ROOT ROUTINE |
| | STA* | RANG | $(X^2 + Y^2 + Z^2)$: RANG, RANG TO N |
| | CLA | R.12 | Z5 |
| | ZEL | | |
| | DIV | N | Z5/RANG |
| | TRA* | ASIN | TRANSFER TO ARC SIN ROUTINE |
| | STA | EL1 | ARC SIN Z5/RANG : EL1 |
| | CLA | X5 | |

| | | | |
|------|------|-----------|---|
| | ZEL | | |
| | DIV | Y5 | |
| | TRA* | ATAN | TRANSFER TO ARC TAN ROUTINE |
| | STA | AZ1, LINK | $TAN^{-1}(X5/Y5) = AZ1$ |
| | | | LINKAGE FROM GENERAL COMPUTE TO ORTM OUTPUT ROUTINE |
| LINK | CLA | SW1 | |
| | TZE | YES, NO | TEST 1ST TIME THRU SW1 |
| YES | ZEL | | FIRST TIME |
| | STL | DLAZ | |
| | STL | DAZ | DEL AZ : DEL AZ/100 : |
| | STL | DLEL | : DEL EL : DEL EL/100 = 0 |
| | STL | DEL, TSW2 | |
| NO | CLA | AZ1 | NOT FIRST TIME |
| | SUB | AZ0 | |
| | STA | DLAZ | COMPUTE DEL AZ |
| | ZEL | | |
| | DIV | | 100 |
| | STA | DAZ | COMPUTE DEL AZ/100 |
| | CLA | EL1 | |
| | SUB | ELO | |

| | | | |
|------|------|------------|--|
| | STA | OEL | COMPUTE DEL EL |
| | | ZEL | |
| | DIV | 100 | |
| | STA | DEL, TSW2 | COMPUTE DEL EL/100 |
| TSW2 | CLA | SW2 | |
| | TZE | RTM, PTPO | TEST SW2 |
| RTM | TRAP | QBCD | TRANSFER TO BCD CONVERSION LOOP FOR CONVERSION OF 6 RTM OUTPUT PARAMETERS |
| | LDR | OUT | OUT TABLE TO R |
| | LDR | TEST, R.10 | TEST TABLE TO Q, GO TO R.10 |

RTM OUTPUT ROUTINE

OUT TABLE AS LOADED INTO R LOOP BY LINKAGE ROUTINE

| | |
|-----|-----------|
| R.0 | (AZ) |
| R.1 | (ΔAZ) |
| R.2 | (ΔAZ/100) |
| R.3 | (EL) |
| R.4 | (ΔEL) |
| R.5 | (ΔEL/100) |
| R.6 | FD(+) |
| R.7 | FD(-) |

| | | | |
|------|------|------------|--|
| R.10 | DIA | , R.11 | SAMPLE TIME ON LINE M |
| R.11 | ALS2 | , R.12 | SHIFT SIGNAL @ LINE M TO SIGN POSITION |
| R.12 | TPL | R.10, R.15 | |
| R.13 | CLA | INIT, REQ | |
| R.14 | DEC | 1831 | |
| R.15 | OD1 | , Q.0 | RESET SWITCH TO POSITION 1 |
| R.16 | DOF | , R.17 | TURN OFF OUTPUT LINE |
| R.17 | OD2 | , Q.0 | STEP SWITCH TO NEXT SWITCH POSITION |
| INIT | CLA | R.0, Q.1 | |
| REQ | STA | TEST, NEXT | |

TEST TABLE IS LOADED INTO Q LOOP BY LINKAGE ROUTINE

| | | | |
|------|-------|------------|--------------------------|
| Q.0 | CLA | (R.0), Q.1 | BRING R.(IND) |
| Q.1 | TPL | Q.2, Q.3 | TEST SIGN |
| Q.2 | CLA | R.6, Q.4 | BRING BCD(+) |
| Q.3 | CLA | R.7, Q.4 | BRING BCD(-) |
| Q.4 | WE4 | Q, Q.5 | WRITE SIGN |
| Q.5 | CLA | (R.0), Q.6 | R.(IND) TO AR |
| Q.6 | ALS 4 | , Q.7 | SHIFT OUT BCD SIGN |
| Q.7 | EDF 6 | , Q.10 | OUTPUT NEXT 7 CHARACTERS |
| Q.10 | CLA | Q.0, Q.11 | |

| | | | |
|------|------|---------------|------------------------------------|
| Q.11 | SUB | Q.12, Q.13 | TEST (IND) |
| Q.12 | CLA | R.5, Q.1 | |
| Q.13 | TZE | R.13, Q.14 | IF IND : 5, REINITIALIZE TEST LOOP |
| Q.14 | CLA | Q.0, Q.15 | IF NOT IND + 1 : IND |
| Q.15 | ADD | R.14, Q.16 | |
| Q.16 | STA | Q.0, Q.17 | |
| Q.17 | STO | Q.5, R.16 | |
| NEXT | STO | TEST + 5, CHK | |
| CHK | CLA | CLK, | |
| | SUB | | |
| | DEC | 8640B31 | |
| | TZE | STOP, UP | |
| STOP | HALT | 0, 0 | |
| UP | CLA | CLK | |
| | ADD | R.14 | |
| | STA | CLK, | GO TO INCREMENT TIME ROUTINE |

APPENDIX C

FADAC MNEMONICS

| | <u>Mnemonic</u> | <u>Operation</u> |
|------|-----------------|------------------------|
| I. | Arithmetic | |
| | ADD | Add |
| | SUB | Subtract |
| | MPY | Multiply |
| | CLA | Clear & Add |
| | CLS | Clear & Subtract |
| | DIV | Divide |
| II. | Store & Load | |
| | STN | Store N |
| | STD | Store D |
| | STA | Store A |
| | STL | Store L |
| | STP | Store (N1) Prog Ad |
| | STO | Store Op Ad |
| | STR | Store R loop |
| | LDR* | Load R loop |
| | LDQ | Load Q loop |
| III. | Transfer | |
| | TPL | Transfer on Plus |
| | TZE | Transfer on Zero |
| | TRA | Unconditional Transfer |
| | TOV | Transfer on Overflow |

| | <u>Mnemonic</u> | <u>Operation</u> |
|-----|-----------------|------------------------------|
| IV. | Shift & Cycle | |
| | ARC | A right cycle |
| | ARS | A right shift |
| | ALC | A left cycle |
| | ALS | A left shift |
| | LRC | Long right cycle |
| | LRS | Long right shift |
| | LLC | Long left cycle |
| | LLS | Long left shift |
| V. | Special | |
| | EXT | Extract |
| | EQS | Equal Search |
| | GES | Greater than or Equal Search |
| | HLT | Halt |
| | HCM | Halt Compute Mode |
| | ICM | Initiate Compute Mode |
| | ZEL | Zero L |
| | IDM | Initiate Display Mode |
| | HDM | Halt Display Mode |
| | ABS | Take absolute Value |
| | RML | Replace A on Minus from L |
| | RMN | Replace A on Minus from N |
| VI. | Serial I/O | |
| | DIA | Discrete Input to A |
| | DOF | Discrete Outp Off |
| | ODI | Outp Dev Stepping - 1 |

| <u>Mnemonic</u> | <u>Operation</u> |
|--------------------------------|-----------------------|
| VI. Serial I/O (Cont'd) | |
| OD2 | Outp Dev Stepping - 2 |
| OD3 | Outp Dev Stepping - 3 |
| ID1 | Inp Dev Stepping - 1 |
| ID2 | Inp Dev Stepping - 2 |
| ID3 | Inp Dev Stepping - 3 |
| NSL | No Solution Light |

| <u>Mnemonic</u> | <u>Interpretation</u> |
|---|------------------------------------|
| VII. Parallel Input/Output Command Summary | |
| WEOT | Write FADAC to Ext Dev in Oct (TT) |
| WFOT | Write FADAC to FADAC in Oct (TT) |
| WEOF | Write FADAC to Ext Dev in Oct (FD) |
| WFOF | Write FADAC to FADAC in Oct (FD) |
| WEDT | Write FADAC to Ext Dev Dec (TT) |
| WFDT | Write FADAC to FADAC Dec (TT) |
| WEDF | Write FADAC to Ext Dev Dec (FD) |
| WFDF | Write FADAC to FADAC Dec (FD) |
| WE6 | Write FADAC to Ext Dev α -6 |
| WF6 | Write FADAC to FADAC α -6 |
| WE5* | Write FADAC to Ext Dev α -5 |
| WF5* | Write FADAC to FADAC α -5 |
| WE4 | Write FADAC to Ext Dev α -4 |
| WF4 | Write FADAC to FADAC α -4 |
| REO | Read Ext Dev in Oct |
| RTO | Read Tape Dev in Oct |
| RKO | Read Keyboard in Oct |

| <u>Mnemonic</u> | <u>Interpretation</u> |
|---|------------------------------|
| VII. Parallel Input/Output Command Summary (Cont'd) | |
| RED | Read Ext Dev in Dec |
| RTD | Read Tape Dev in Dec |
| RKD | Read Keyboard in Dec |
| RE6 | Read Ext Dev in α -6 |
| RT6 | Read Tape Dev in α -6 |
| RM6 | Read Mag Tape in α -6 |
| RK6 | Read Keyboard in α -6 |
| RE5 | Read Ext Dev in α -5 |
| RT5 | Read Tape Dev in α -5 |
| RM5 | Read Mag Tape in α -5 |
| RK5 | Read Keyboard in α -5 |

APPENDIX D

DEFINITION OF SYMBOLS OTHER THAN INPUTS, USED IN GENERAL COMPUTATION ROUTINE

| <u>Symbolic Notation as Shown on Program Listing</u> | <u>Symbolic Notation as Shown on Flow Diagram</u> | <u>Definition</u> |
|--|---|--|
| THCS | Ocs | Geocentric Latitude |
| 1/297 | 1/297 | Eccentricity Constant |
| XS, YS, ZS | Xs, Ys, Zs | Station Coordinates |
| TOB | TOB | Time from Epoch (in binary) |
| EJ | EJ | Let MA = EJ and iterate until $ EJ1 - EJ \leq 0.01^\circ$; then EFIN = EJ1, and EJ1 = result of each iteration. (See Eq 4.) |
| ANOM | ANOM | Semi-major axis normalized to Re |
| X1, Y1 | X1, Y1 | Satellite Coordinates in Orbit Plane |
| CHIO | Ψ_0 | Argument of Perigee at Epoch |
| X2, Y2 | X2, Y2 | Satellite Coordinates Normal to Orbital Plane |
| X3, Y3, Z3 | X3, Y3, Z3 | Where X3 is along Ascending Mode, Y3 is in equatorial plane 90° E of X3 and Z3 is along Earth's axis. |
| GHAR | GHAR | Greenwich Hour Angle of Aries at Epoch |
| 0.250683 | ω_E | Earth's rotation rate in degree/min. |

| <u>Symbolic Notation as Shown on Program Listing</u> | <u>Symbolic Notation as Shown on Flow Diagram</u> | <u>Definition</u> |
|--|---|-------------------------------------|
| X4, Y4, Z4 | X4, Y4, Z4 | Earth Rotating Coordinates |
| RS | RS | Radius center of Earth to station |
| RG | RG | Radius center of Earth to satellite |
| X5 | X5 | Eastward) |
| Y5 | Y5 | Northward) Local Coordinates |
| Z5 | Z5 | Zenith) |

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|--------|----|--------|----|--------|----|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Antenna Position Programmer System Satellites, tracking Computer, Gun Direction M18 (FADAC) | | | | | | |

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